Chapter 10.

Variable Timing (VVT) and Variable Lift Systems.

If one considers the enormous diversity of camshaft profiles in terms of lift, duration, phasing and so on, there are quite a few choices about how variability of valve events might be achieved and the consequent effect on engine performance in terms of fuel efficiency, exhaust emissions and power output.

From the very earliest days of the internal combustion engine variable valve event systems have abounded, sometimes as actual applied hardware, at other times never progressing beyond the proposal stage. For example very early Cadillacs from around the start of the 20th century had a single cylinder engine with a variable lift inlet valve as a means of controlling power and not long after that the Rover company were making their engines with three dimensional cams for the same purpose and also to enhance engine braking at a time when other methods of braking were rather rudimentary.

Different variable valve event schemes came and went over the years but the attitude of most engine designers was that the easiest way to overcome any shortage of torque is to simply make the engine bigger. Consequently nearly all production engines get stretched in size over the years, sometimes well beyond anything that would have been foreseen by the original design team.

Even in racing there has never been much interest, often because of a reluctance to add something that might compromise a highly stressed valve mechanism and also because the working speed range is usually quite narrow. The operating clearances between valves and pistons during the overlap period are usually so minute that there simply isn’t any scope to try to vary the valve timing. It is also easily forgotten that drivers of very high powered racing engines sometimes deliberately drop to lower engine speeds, where torque is less, for easier control of traction out of slow corners. At a street circuit like Monaco it is not unknown for 18,000 r.p.m. F1 engines to be deliberately run as low as 6000 r.p.m. around the tightest corners.

The real impetus for exploiting variable valve events came from the imposition of serious emission control legislation in the period commencing around 1970. Most engines of the time had simple pushrod valve gear with all the cams aligned on one shaft, which rather limited the potential for advance and retard cam mechanisms so there wasn’t much progress, although there was no shortage of schemes and proposals. Only when modern overhead twin cam designs became common did it become feasible to consider varying the timing of one cam separately from the other.

The Jaguar XK twin cam would hardly have been thought of as a modern design by the early 1970s but it was known that advancing just the inlet cam by 10 degrees could reduce NOx emissions in an FTP 75 emission test by just over 20%. This was accompanied by a 2.5% loss of peak power on top of the losses already incurred from reduced compression and addition of a catalyst exhaust system so was not considered welcome. A cam advance/retard system would obviously have been useful and there was no shortage of system proposals but none had any track record of proven reliability in service so Jaguar’s engineers had to persevere with alternative emission control methods.

The preference for using technology that had the best chance of providing the required long term durability to reduce exhaust emissions was unanimous and it was not until about 1980 that a production car first appeared with a viable means of varying cam timing. Since then other manufacturers and industry suppliers have devised a richly diverse range of solutions to the modern need for variation of the valve events. Some useful examples follow.

Variable Valve Timing.

Alfa Romeo had dabbled with a number of VVT mechanisms in the 1970s so perhaps it was no surprise when they became the first manufacturer to introduce a production engine equipped with variable cam timing.

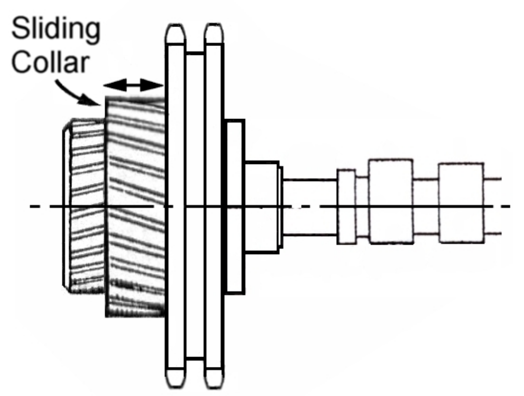

Fig. 10.1 Principle of sliding collar with concentric helical splines between the sprocket and the camshaft.

Alfa called their advance/retard device a 'variator' and it used a really quite straightforward mechanism based on simple technology (Fig. 10.1). The chain sprocket was formed with internal helical splines inside which a sliding collar with matching splines engaged. The inside of the collar was formed also with helical splines but of opposite hand which engaged with matching splines on a boss attached to the camshaft. The use of two opposed sets of splines in this way allows more angular movement to be possible with splines formed to a relatively gentle helix thereby avoiding excessive friction and end loading

The sliding collar also formed part of a hydraulic ram so that oil pressure could shift it laterally against a return spring so that the helical splines would cause the sprocket to shift radially with respect to the camshaft thereby advancing the camshaft by 25 degrees. The oil pressure was controlled by a solenoid valve so the mechanism had only two operating states – a baseline retarded position or fully advanced.

A problem with this sort of mechanism is that there has to be some working clearance, however slight, around the splines so the vicious torsional loads which can sometimes be generated by a valve train can cause chatter and consequent wear. Only having two states at the extreme ends of travel, this tends to be less problematical than trying to use intermediate positions. Nevertheless fully variable systems have been used, BMW's Vanos being one example, but this used a double sided hydraulic actuator which probably provided a useful damping function. Application to six cylinders would also have helped to attenuate the torsional issues. Toyota also produced something similar.

An alternative is to shift the slack in a timing chain to before or after the sprocket in question. This has been applied to a secondary chain between camshafts with a tensioner mechanism that moves the slack from before to after the inlet cam sprocket (Fig. 10.2). Intermediate positioning is also possible but the method has to include a means of dealing with normal chain stretch in service and the tensioner pad can suffer when deflecting the chain run on the loaded side as in the lower diagram. It also requires that the primary chain drives the exhaust camshaft which is less ideal with Vee engines. The method has not found much favour because of such issues.

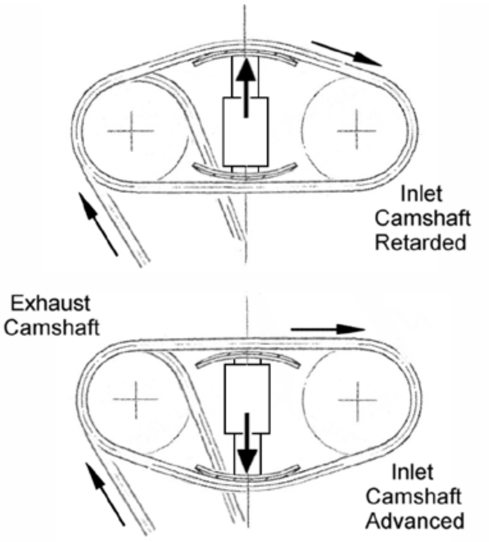

Fig. 10.2 Inlet cam timing variation by chain tension shifting.

Many early systems only varied the inlet valve timing because of the more important control of the inlet valve closing point and the overlap duration, so shifting the exhaust cam timing has less effect – gains at the opening point are more or less negated at the closing point and vice versa.

Later systems often do apply timing shift to the exhaust camshaft so that, as well as a modest effect on performance, it may be used to provide extra control of EGR. Advancing the exhaust timing can also be useful for faster catalyst light-off from cold by raising the exhaust temperature due to the earlier opening point, whilst the earlier closing helps to retain any HC residues in the chamber extremities, helpful in meeting emission targets like SULEV.

It is usual to retard the inlet cam for minimal overlap at idle, then advance it for early inlet closing and more overlap in part throttle cruise, then retard it again for late closing as maximum power is approached. Thus exhaust dilution is minimized for good idle quality, NOx is reduced by promoting EGR in cruise conditions, simultaneously improving low and mid-range torque by closing the inlet valves early, then breathing at high speed can be improved by delaying the inlet valve closure point. However the overall cam duration is shorter than would be considered ideal for high speed operation so there is still an element of compromise involved, although the widening of the usable torque band is undeniably of benefit.

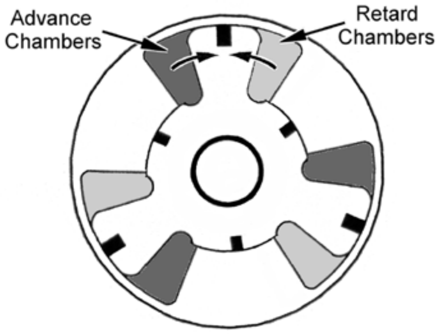

Fig. 10.3 Hydraulic vane VVT actuator.

To obtain the advantages possible by applying differing amounts of phase change to the cam shaft according to circumstances, the hydraulic vane actuator provides an alternative solution that is less likely to suffer problems from valve train torsional loads. The principle is based on a rotor with several radial vanes mounted within a housing shaped to form chambers around the vanes (Fig. 10.3). By controlling pressurised oil flow into these chambers the phasing of the camshaft relative to the sprocket can be finely controlled using feedback from a sensor to detect the position of the shaft.

This type of actuator is another example that took many years to evolve from experimental projects in the early 1970s. The seemingly ideal arrangement also has certain disadvantages. The speed of operation is significantly affected by changes of oil viscosity which can compromise the action at very low and very high temperatures so the oil pump capacity may need to be increased and oil temperature monitored by the control system. Nevertheless it is a useful mechanism in the pursuit of better fuel efficiency and reduced emissions.

Borg Warner devised a most interesting variant of this type of actuator that avoids the problems described. They call it Cam Torque Actuated (CTA) technology which actually makes use of the spasmodic torsional loadings that are inherent to any valve gear drive mechanism to shift oil from the advance to retard chambers or vice versa through a system of one way valves as directed by a solenoid operated spool valve. A connection to the engine oil supply is only necessary for topping-up purposes. A cam position sensor provides feedback for the ECU to activate the spool valve as required and the system can change the cam phasing from full retard to full advance in about 1/3 of a second,

Borg Warner even thought about provision for multi-cylinder in line engines that produce weaker torsional reversals by use of an eccentric chain sprocket to provoke the necessary forces artificially.

8 pages follow.